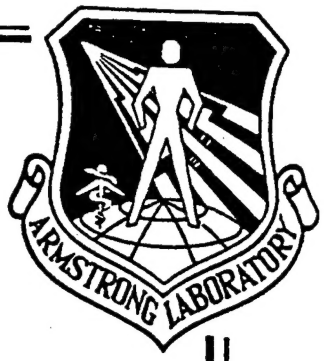
AL/CF-TR-1995-0111



ARMSTRONG LABORATORY

HUMAN ENZYMATIC CHANGES ASSOCIATED WITH IMPACT FORCES IN THE LATERAL (Gy) AXIS

Andrew Tong

CREW SYSTEMS DIRECTORATE
BIODYNAMICS AND BIOCOMMUNICATIONS DIVISION
WRIGHT-PATTERSON AFB OH 45433-7008

Gaylen Johnson

WRIGHT STATE UNIVERSITY
DAYTON OH 45324

DECEMBER 1993

FINAL REPORT FOR THE PERIOD MAY 1992 TO MAY 1993

AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433-6573

NOTICES

When US Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Armstrong Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
8725 John J. Kingman Rd.
STE 0944
Fort Belvoir, VA 22060-6218

TECHNICAL REVIEW AND APPROVAL

AL/CF-TR-1995-0111

The voluntary informed consent of the subjects in this research was obtained as required by Air Force Instruction 40-402.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

Thomas J Moore

THOMAS J. MOORE, Chief
Biodynamics and Biocommunications Division
Crew Systems Directorate
Armstrong Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	~~March 1995~~	Final for period May 92 - May 93

4. TITLE AND SUBTITLE
Human Enzymatic Changes Associated with Impact Forces in the Lateral (Gy) Axis

5. FUNDING NUMBERS
PE: 62202F
PR: 7231/7231
TA: 25/24
WU: 01/01

6. AUTHOR(S)
Andrew Tong
Gaylen Johnson

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Armstrong Laboratory, Crew Systems Directorate
Biodynamics and Biocommunications Division
Human Systems Center
Air Force Materiel Command
Wright-Patterson AFB OH 45433-7008

8. PERFORMING ORGANIZATION REPORT NUMBER
AL/CF-TR-1995-0111

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Escape and impact protection systems expose aircrew to short duration impact accelerations of significant amplitude. Numerous animal, manikin, and human studies have explored impact tolerance limits in the Gx and Gz axes, but very few studies have considered the Gy axis. There is an increased risk of injury when impact forces in the Gy direction are employed. There has been no documented attempt to use biochemical analysis to help establish safe exposure levels to impact forces. In one recent study, ten human subjects were exposed to +Gy impact accelerations of various amplitudes and durations at the Armstrong Laboratory Horizontal Impact Accelerator facility at Wright-Patterson AFB OH. Two types of data were collected from this study. First, biodynamic data on human response to +Gy impacts over a broad range of acceleration amplitudes and durations. Second, blood samples were collected to look at subclinical, but possibly significant, enzymatic changes following +Gy impact forces. This report documents a methodology to measure subclinical, but detectable enzymatic changes associated with impact forces in the Gy axis. Furthermore, the authors conclude from these changes that the lateral impact forces employed in this study were well within the limits of human tolerance.

14. SUBJECT TERMS
Gy, impact, acceleration, escape, impact protection, limits ejection, biochemical analysis, enzymatic changes

15. NUMBER OF PAGES
18

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

THIS PAGE LEFT BLANK INTENTIONALLY

PREFACE

This effort was jointly supported by the Combined Stress Branch Task 723125; Aircrew Performance Enhancement) and by the Escape and Impact Protection Branch (Task 723124; Aeromedical Criteria for Escape Systems) of the Biodynamics and Biocommunications Division of Armstrong Laboratory.

Blood analyses were accomplished by personnel of the Toxicology Division (AL/OET) with support provided under Contract Number F33615-89-C-0574 with Systems Research Laboratories, Inc., 2800 Indian Ripple Road, Dayton OH 45440-3696 with funds from Task 723125. Support for the impact facilities, data acquisition instrumentation, and data processing systems were provided by the Scientific Services Division of DynCorp under Air Force Contract F33615-91-C-0531 with funds from Task 723124.

The work reported herein was performed while Dr. Gaylen Johnson of Krug Life Sciences was a Resident in Aerospace Medicine at Wright State University. This work was "piggybacked" on a protocol entitled, "Investigation of Human Response to Varied -Gy Impact Duration and Amplitude", Joseph Strzelecki, Principal Investigator. The Horizontal Impact Accelerator (HIA) in the Escape and Impact Protection Branch was used to simulate lateral impact acceleration.

The authors wish to thank the personnel of the Toxicology Division and the personnel of the Escape and Impact Protection Branch (AL/CFBE). The authors wish to give special thanks to Dr. William Albery of the Combined Stress Branch and Dr. Stephen Popper of the Escape and Impact Protection Branch for their generous support and technical assistance in publishing this report.

The authors also would like to thank Dr. Satya Sangal of Wright State University for his assistance with the statistical analyses and the study volunteers for their willingness to participate in this effort.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Escape and impact protection systems, such as ejection seats or ejection capsules, expose aircrew to short duration impact accelerations of significant amplitude. Many studies have explored the biodynamic responses of humans to impact acceleration forces. Most of these studies were performed using impact forces in the Gx and Gz axes, instead of forces in the Gy axis. (2,4,10,13,14,15,16,17,18,20,22) There is an increased risk of injury to the internal organs when impact forces are applied in the Gy axis. (9,12,16,20,21,22) Medical trauma data bases confirm that Gy (lateral) impacts result in more frequent, and more severe, abdominal injury than Gx (frontal) impacts. There has been no documented attempt to use biochemical analysis to help establish safe exposure levels to impact forces. This report documents a methodology to measure subclinical, but detectable enzymatic changes, associated with impact forces in the Gy axis.

Impact Acceleration and its Relevance to the USAF

Impact acceleration forces are defined as those lasting less than 1 second in duration. The standard acceleration coordinate terminology defines Gx axis as front-back, Gz axis as head-toe, and Gy axis as side-side.

Existing United States Air Force impact protection/escape systems have traditionally been built using design limits based on the Dynamic Response Index (DRI). The DRI is a number whose value is related to the maximum displacement of a spring (spine) in a single-degree-of-freedom lumped-parameter mass-spring-viscous damper model when such a model is driven by the seat acceleration time-history. The magnitude of

the DRI is related to the probability of spinal injury, defined as presence of radiographic evidence of fracture, based on both laboratory and USAF operational ejection spinal injury data.

Current USAF impact acceleration research seeks to expand the present day DRI model into a three-dimensional "six-degree-of-freedom model" to better guide designers of future aircraft escape mechanisms. The six-degree-of-freedom model is a model of human response and injury potential for short duration acceleration. This model assumes that the human upper torso response to impact acceleration can be modeled by independent one-degree-of-freedom, spring-mass-damper systems displacing along or rotating about three principal axes of a Cartesian coordinate system. This model assumes that the responses of the one-degree-of-freedom models can be combined to represent the effects of off-axis or combined acceleration inputs. In order to develop a three dimensional model, one must first have good reliable human data in all three primary axes. Traditionally, exploration of human limits to impact forces have focused on the spinal model. However, it is probable that subclinical enzymatic changes occur at impact levels significantly below levels that would cause radiographic changes in the spine.

Numerous animal, manikin, and human studies have explored impact tolerance limits in the Gx and Gz planes, but very few studies have considered human responses to impact forces in the Gy plane. In this study, ten human subjects were exposed to +Gy impact accelerations of various amplitudes and durations at the Armstrong Laboratory Horizontal Impact Accelerator facility at Wright-Patterson AFB, Ohio. Two types of data were collected from this study. First, biodynamic data on human response to +Gy impacts over a broad range of acceleration amplitudes and durations. Second, blood samples were collected to look

at subclinical, but possibly significant, enzymatic changes following +Gy impact forces. This report documents a methodology to measure subclinical, but detectable enzymatic changes associated with low level impact forces.

Mechanisms of Impact Acceleration Injury

These are two basic mechanisms for tissue injury during impact acceleration. One is "direct" injury and it is caused by crush trauma from physical contact. The other is "indirect" injury that results from transmitted pressure waves following the impact. The impact causes a transfer of energy from the body wall to the viscera during impact. (1,5,6,17,18) Each organ of the viscera has its own set of viscoelastic properties. Furthermore, the viscoelastic limits of the target organs may be exceeded based on either amplitude or duration of the impact, or both. In addition, the shear force, acting at organ attachments, can lead to tear injuries. (5,6,17) Lastly, organs striking against stiff structures may also cause injuries to the organs. (5,17)

Amplitude and duration of impact are two important variables determining the likelihood of injury. Generally, the higher the amplitude and the longer the duration, the more likely it is that injury will occur. Durations longer than 0.20 seconds are more likely to exceed the natural dynamics of the organs. (5,17) Amplitudes of greater than 12 Gs with durations longer than 0.30 seconds are most likely to result in clinical injury in the +Gy direction. (7,21)

MATERIALS AND METHODS

The impact tests were conducted at the Impact Accelerator facility of Armstrong Laboratory (Figure 1), Wright-Patterson Air Force Base (WPAFB), Ohio, over a three and a half month period. Appropriate safety precautions were taken and the research was approved by the WPAFB Armstrong Laboratory Human Use Review Committee.

Eight subjects participated in the enzymatic portion of the study. The subjects were volunteer members of the Impact Accelerator Test Panel and were on active duty throughout their participation in the study. As members of the test panel, they were subjected to exhaustive screening prior to coming onto the panel and are subjected to an annual physical examination. All subjects were also examined before and after each exposure by a qualified physician. All eight subjects were certified to be in good health by an independent Armstrong Laboratory physician. The original test plan called for twelve exposures with amplitudes of 3.5 to 8.0 Gs and pulse durations of .030 to .265 seconds.

Partly due to safety concerns arising from our literature search, the investigator of the biodynamic impact portion of the study opted to impose a ceiling of 7.0 Gs AND decrease the pulse duration for all but one of the exposures. Exposures with the lower amplitudes and durations were conducted first. The actual exposure conditions are listed in Table 1, with amplitudes of 4 to 7 G and exposure durations of 0.030 to 0.265 seconds. This decreased the likelihood that the enzymatic portion of the study would be able to detect significant enzymatic changes resulting from the impacts. The need for documenting enzymatic changes as a result of impact forces did not justify risking the subjects' well being.

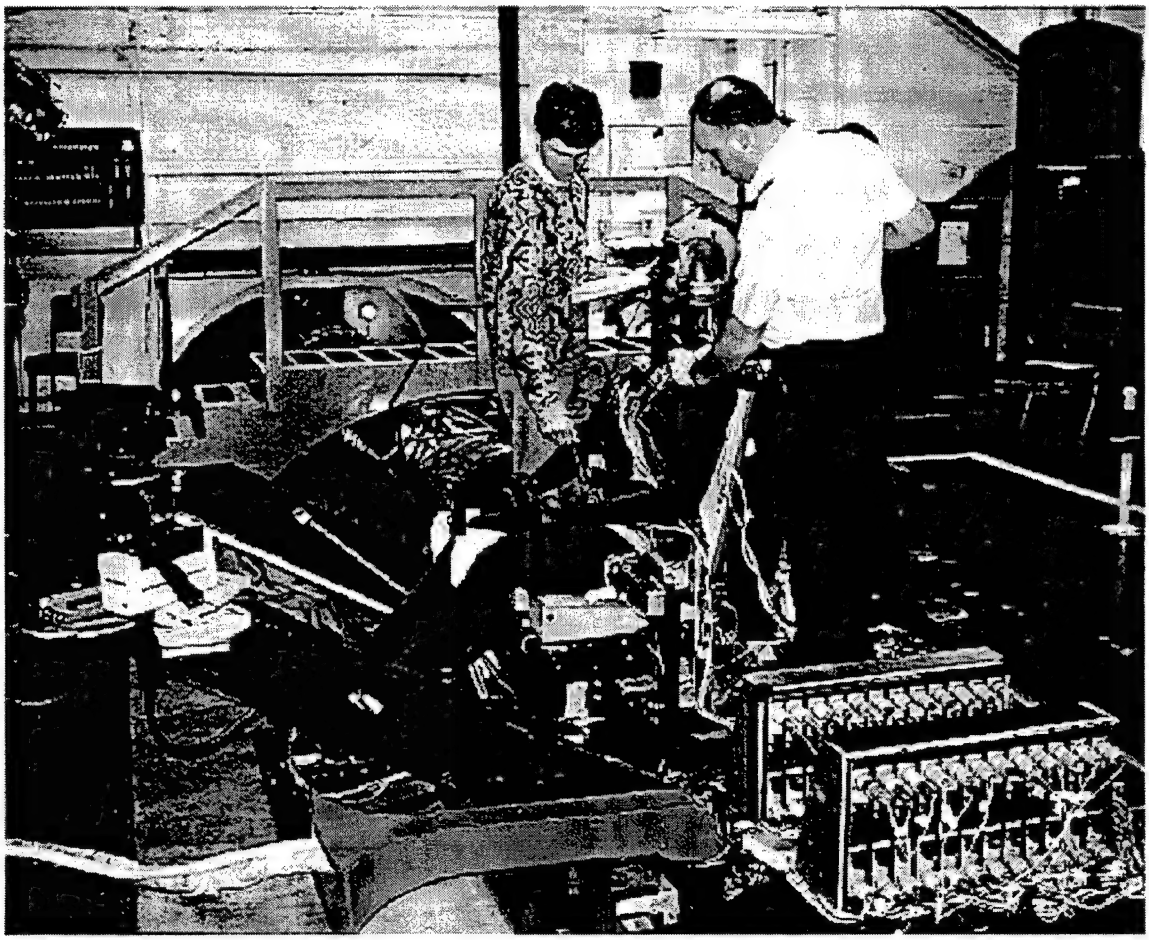


FIGURE 1. HORIZONTAL IMPACT ACCELERATOR

TABLE 1. IMPACT CONDITIONS

CONDITIONS	AMPLITUDES (Gs)	DURATION (seconds)
A	4	0.150
B	5	0.150
C	6	0.150
D	7	0.150
E	6	0.030
F	6	0.064
G	6	0.210
H	6	0.265

Blood samples were collected from the antecubital veins using standard sterile phlebotomy techniques. Baseline samples were obtained from each subject. One blood sample was taken from each participant immediately before each impact and again two hours and twenty-four hours after each impact, for a total of three samples for each impact exposure. Once the study was explained to them, the subjects complied very well despite the frequency of blood sampling.

The blood samples were stored in a chilled transport container until delivery to the Armstrong Laboratory Toxicology Division. All blood specimens were delivered for analysis within 2 hours of collection. The enzymes assayed include blood urea nitrogen (BUN), amylase, lipase, aspartic aminotranserase (AST), alanine aminotransferase (ALT), creatinine kinase (CK), lactic dehydrogenase (LDH), gamma glutamyltransferase (GGT), and alkaline phosphatase.

The subjects experienced no more than one impact exposure each week. All subjects pledged to abstain from alcohol intake and agreed to not undergo a drastic change in their exercise routines throughout the study period. They were briefed on the parameters surrounding the test prior to each exposure. Each subject was placed in a 40-G, man-rated seat in compliance with military standard. Each subject wore a HGU-26/P helmet, socks, and cutoff long aircrew underwear. Each subject was restrained using two shoulder straps, pretensioned to 10 +/- 3 pounds, a PCU-15/P harness, and an ACES II lap belt, each pretensioned to 20 +/- 1 pounds. Solid blocks were used to prevent hip motion during the impact. Ballast was used to keep the impact sled at a constant weight for each subject and impact run.

The data were analyzed using a mixed model analysis of variance (ANOVA) design. SAS™ statistical software was used. The significance level was set at 0.05. Subjects, impacts, and blood sample measurements were the variables considered, with analysis for interaction between each one of the variables.

The eight subjects that took part in this enzymatic study were all male (mean age 30.6 +/- 5.5 S.D. years). The subjects participated as follows: 2 participated in all 8 cells; 2 participated in 7 cells; 3 participated in 6 cells; and 1 participated in 4 cells. Statistical allowances were made for the missing data and were considered prior to interpretation of the results.

RESULTS

One subject experienced petechiae on the abdomen following two medium amplitude impact runs. No subject experienced serious injury during the impact exposures. All investigated enzymes displayed expected subject variability. There were no significant differences (at the .05 level) found in the analysis of subjects and sample interactions. There were no significant differences found in the analysis of impact and sample interactions. The only significant differences were found in the interaction between subjects and impacts. Enzyme levels for AST and LDH were found to have significant differences. Table 2 lists the F-values for mixed model ANOVA results for the interactions between impact and samples for each enzyme measured.

TABLE 2. F-VALUES FOR MIXED MODEL ANOVA RESULTS

ENZYMES / Variables	BUN	ALT	AST	AMY-LASE	LIP-ASE	CK	LDH	ALK. PHOS.	GGT
SUBJECT (V_1)	52.38*	102.9*	22.79*	41.79*	10.38*	44.38*	3.02*	48.13*	276.9*
IMPACT (V_2)	2.70*	4.20*	3.91*	2.06	1.19	8.87*	1.90	0.33	9.31*
TIME (V_3)	0.78	0.71	3.29*	1.20	0.24	0.27	1.04	0.29	0.10
V_1 vs. V_2	0.56	1.07	3.08*	0.89	0.65	0.69	4.17*	0.21	1.54
V_1 vs. V_3	0.99	0.3	3.32	1.14	0.32	0.56	0.92	0.33	0.09
V_2 vs. V_3	0.85	0.77	0.70	0.81	0.75	0.72	0.68	1.06	1.07

* = significant ($\alpha = 0.05$)

DISCUSSION

All subjects had baseline enzyme levels within the normal range for their age and gender. The statistical differences in "measured enzyme levels" for each subject demonstrated the normal fluctuations that can be seen within the normal range. At no time throughout the course of this study did enzyme levels depart from this normal range. One subject developed petechiae on his abdomen which was attributed to voluntarily generated high abdominal pressures against the straps, while bracing immediately prior to the impact run.

Of the three ANOVA of interactions between subjects, impacts, and samples, the interaction between samples and impacts was the most important. No statistically significant differences were seen for this interaction.

The ANOVA of subjects vs. samples was interesting, but less meaningful since our sample size was small. Differences seen here could be due simply to normal subject variability. Therefore, it was not surprising that there was no significant difference for the interaction between blood sample measurements and subjects.

In the ANOVA of subjects vs. impacts, statistically significant differences for two enzymes were found when the interaction between subjects and impacts was considered. The changes for AST and LDH were found to be statistically significant at the .05 level. However, these are two enzymes known for their likelihood to vary from week to week and are particularly sensitive to normal use of the muscles. Both enzymes are non-specific enzymes found in many tissues of the body. Other enzymes in our battery of tests, such as lipase or amylase, are more organ specific

and would not be expected to vary as much from sample to sample. There were no statistically significant differences found in the more specific enzymes.

The timing of the blood sampling was a compromise based on potential problems with subject availability and logistical considerations. The sensitivity of the study might have improved with better timed blood samples but it was impractical to have the subjects present themselves for blood sampling between the hours of midnight and 8:00 A.M.

CONCLUSIONS

By design, the lateral impact forces used in this study were not likely to cause injuries to the subjects. Therefore, it did not surprise us that no statistically significant changes were detected on a subject population of eight. The fact that differences were found in the levels of what are normally fluctuating enzymes (AST, LDH), but none in the more specific enzymes supports the validity of our collection and measurement procedures. Thus, the methodology described is a safe and useful adjunct to radiographic and clinical examinations for monitoring human subjects being exposed to impact forces. The results also support a conclusion that the impact forces employed in this study were well below the threshold of human tolerance to lateral impact forces.

REFERENCES

1. Beckman DC, McElhaney VL, Stalnaker RL. Impact tolerance - abdominal injury. Ann Arbor MI: The University of Michigan, Publication of the Highway Safety Research Institute, 1971.

2. Beeding EL. Human forward facing impact tolerances. Abstract of Oral Presentation to the Annual Meeting. Aerospace Medicine. 1961, 32:220.

3. Brinkley JW, Shaffer JT. "Dynamic Simulation Techniques for the Design of Escape Systems: Current Applications and Future Air Force Requirements" in AFAMRL-TR-71-29, 1971.

4. Brown RS, Rothstein JD, Foster P. Human response to predicted Apollo landing impacts in selected body orientations. Aerospace Medicine. 1966, 37:394-98.

5. Cooper GJ, Taylor DEM. Biophysics of impact injury to the chest and abdomen. Journal of the Royal Army Medical Corps. 1989, 135:58-67.

6. VonGierke HE. Response of the body to mechanical forces - an overview. Annals of the new York Academy of Sciences. 1968, 125:172-86.

7. Glaister DH. Human Tolerance to Impact. Injury: The British Journal of Accident Surgery. 1978, 9:191-8.

8. Kornhauser M, Gold A. Application of the impact sensitivity method to animate structures. In: Impact Acceleration Stress: Proceedings of a Symposium. Washington DC: National Academy of Sciences-National Research Council, Publication 977, 1962:333-44.

9. Lombard CF, Bronson SD, Thiede FC, Close P, Larmie FM. Pathology and physiology of guinea pigs under selected conditions of impact and support restraint. Aerospace Medicine. 1962, 35:860-5.

10. Paolucci G, Blundo G, Balla A. Behavior of some serum enzyme activities in man, after crash accidents, causing massive injuries. In: Linear Accelerations of Impact Type, Advisory Group for Aerospace Research and Development (AGARD), North Atlantic Treaty Organization. Presented at the Aerospace Medical Specialists Meeting, Oporto, Portugal, 1971.

11. Payne PR. The dynamics of human restraint systems. In: Impact Acceleration Stress: Proceedings of a Symposium. Washington DC: National Academy of Sciences-National Research Council, Publication 977, 1962:195-257.

12. Rouhana SW, Lau IV, Ridella SA. Influence of velocity and forced compression on the severity of abdominal injury in blunt, non-penetrating lateral impact. Journal of Trauma. 1985, 25:490-500.

13. Rubashkina LA. Some clinical-biochemical indices of human tolerance to impact acceleration. Koshmichesdaya Biologiya I Meditsina. 1970, 4:71-5.

14. Rutledge R, Thompson M, Oller D, Meredith W, Moylan J, Clancy T, Cunningham P, Baker C. The spectrum of abdominal injuries associated with the use of seat belts. The Journal of Trauma. 1991, 31:820-6.

15. Siegel JH, Dalal AR, Burgess AR, Young JW. Pattern of organ injuries in pelvic fractures: impact force implications for survival and death in motor vehicle injuries. Accident Analysis and Prevention. 1991, 22:457-66.

16. Snyder RG, Snow CC, Young JW, Price GT, Hanson P. Experimental comparison of trauma in lateral (+Gy), rearward facing (+Gx), and forward facing (-Gx) body orientations when restrained by lap belt only. Aerospace Medicine. 1967, 38:889-894.

17. Stapp JP. Jolt effects of impact on man. In: Impact Acceleration Stress: Proceedings of a Symposium. Washington DC: National Academy of Sciences-National Research Council, Publication 977, 1962:123-30.

18. Stapp JP. Human tolerance to deceleration. American Journal of Surgery. 1957, 93:734-40.

19. Stech EL, Payne PR. "Dynamic Models of the Human Body," In AAMRL-TR-66-157. 1969.

20. Viano DC, Lau IV, Asbury C, King AI, Begeman P. Biomechanics of the human chest, abdomen, and pelvis in lateral impact. Accident Analysis and Prevention. 1989, 21:553-74.

21. **Weiss MS, Matson DL, Brinkley JW. Human response to several impact acceleration orientations and patterns. Aerospace Medicine. 1963, 34:1122.**

22. **Weiss MS, Matson DL, Mawn SV. Guidelines for human exposure to impact acceleration: update A. New Orleans, LA. Naval Biodynamics Laboratory, 1989, NBDL-89R003.**